

Sustained Radiative Divertor in High-Performance Grassy-ELM Regime with Metal Wall towards Long-Pulse Operation in EAST

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Simultaneous control of transient heat load induced by large-amplitude edge-localized modes (ELMs) and steady-state heat load on divertor targets under metal wall environment is crucial for steady-state operation of future tokamak fusion reactors, such as ITER and the China Fusion Engineering Test Reactor (CFETR). In the recent experiments, sustained detachment without confinement degradation has been achieved for the first time in the Experimental Advanced Superconducting Tokamak (EAST) in high-performance H-mode plasmas with small grassy ELMs by using a newly developed integrated-feedback-control technique, in which we first use electron temperature (T_{et}) measured by divertor-target Langmuir probes to identify the onset of detachment, and then switch to the feedback control of divertor radiation just beneath the X point, where a steep gradient in the radiation profile is present. The feedback is performed through pulsed impurity seeding with mixed gas (50% neon and 50% D₂ or argon/D₂) from the outer target plate near the strike point in the upper tungsten divertor [1]. T_{et} was successfully maintained in the range of 5-8 eV, and peak temperature on the target surface ($T_{IR,peak}$) was maintained at ~ 180 °C, based on infrared camera measurements. The plasma stored energy and H₉₈ factor keep nearly constant over the entire feedback-control period. It thus offers a highly promising plasma control scenario suitable for long-pulse high-performance H-mode operation in EAST, which is potentially applicable to future steady-state fusion reactors, as an integrated solution for the control of both ELM-induced transient and steady-state divertor heat loads. The experiments were conducted with water-cooled metal wall, low plasma rotation and dominant electron heating, as projected for a fusion reactor. In addition, these experiments demonstrate good compatibility of the high-performance grassy-ELM regime with radiative divertor. The key plasma conditions for access to the grassy-ELM regime in a metal wall environment have been discovered recently, for the first time, in EAST [2]. First, a wide pedestal and a low pedestal density gradient are essential for access to this regime. Second, the grassy-ELM regime is achieved with a relatively high q_{95} (>5.2) in EAST. High q_{95} reduces the risk of major disruptions and facilitates access to a higher bootstrap current fraction which is essential to achieve steady-state operation with reduced power requirement for external current drive. Furthermore, the grassy ELM regime exhibits strong impurity exhaust capability, as well as a relatively high plasma density at the separatrix, which enhances boundary impurity screening and facilitates divertor detachment at a relatively low pedestal top density, which are essential to minimize the influence on the core confinement, thus beneficial for long-pulse H-mode operation with a sustained radiative divertor in a metal wall environment.

[1] L. Wang, et al., Nucl. Fusion 59 (2019) 086036

[2] G.S. Xu, et al., Phys. Rev. Lett. 122 (2019) 255001